SOME OBSERVATIONS ON THE TRANSVERSE ROTATIONS OF THE HUMAN TRUNK DURING LOCOMOTION [a] [b]

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ABSTRACT

The transverse rotations of the human pelvis and shoulder girdle during walking were studied and compared in 10 young men and 10 young women. Three sets of measurements were made for each subject: transverse rotation of the pelvis, transverse rotation of the shoulder girdle, and simultaneous transverse rotations of the pelvis and the shoulder girdle. All measurements were made while the subjects walked on a level treadmill at each of three different speeds (2.93 km./hr., 4.39 km./hr., and 5.86 km./hr.). A broad leather pelvic belt and two shoulder clamps connected by a crossbar were used. A linear variable differential transformer in a special mount which converted angular motion to linear motion was used to measure the angular displacements. Recordings were made with a Tektronix storage oscilloscope at sweep speeds of 0.2 sec./cm., 0.5 sec./cm., and 1.0 sec./cm. For several trial runs, a specially developed goniometer was used to measure the rotations.

In general, no great differences between men and women were found in any of the average amounts of rotation. Nearly all the highest individual values were measured in men and the lowest in women. Rotations of the pelvis increased in amount and became more uniform in pattern as speed increased, whereas rotations of the shoulder girdle de-

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creased at higher speeds. When the subjects walked at 4.39 km./hr., the sum of separately measured rotations of the pelvis and the shoulder girdle exceeded, in all but two cases, the amounts of directly measured counterrotations of the pelvis and the shoulder girdle. This finding suggests that, at this speed of walking, the rotations of these two segments of the body are not exactly 180 deg. out of phase.

I. INTRODUCTION

During normal human locomotion at moderately fast rates, the trunk rotates in the transverse plane in such a way that the pelvis and the shoulder girdle are approximately 180 deg. out of phase. While this is a commonplace observation, little has been written about the precise magnitude and character of these rotations. Elftman (*4*) used an analytic method to calculate rotation of the trunk. Actual measurements of the magnitude of the transverse rotation of the trunk have been made (*5, 7, 9*). The purpose of the present study was 1. to introduce new techniques suitable for making measurements of motions of the trunk; 2. to repeat, using these new techniques, some of the measurements made by Levens and co-workers (*7*), Saunders and co-workers (*12*), and Murray and co-workers (*9*); 3. to compare transverse rotations of the male and female trunks; and 4. to determine the character of angular displacement of the trunk.

II. METHOD

Subjects

Twenty normal subjects were studied, 10 men and 10 women. The men had an age range of 19 to 35 years and the women, 21 to 22 years. The height, weight, and type of body build of the subjects are summarized in Table 1. None of the subjects was accustomed to strenuous or unusual activities. Therefore, the measurements made on this group of subjects are probably representative of the general population, within the limits defined, even though the sample was small.

Measurements

Three sets of measurements were made for each subject: 1. transverse rotation of the pelvis, 2. transverse rotation of the shoulder girdle, and 3. simultaneous transverse rotations of the pelvis and the shoulder girdle. All measurements were made while the subjects walked on a level treadmill at each of three different speeds (2.93 km./hr., 4.39 km/hr., and 5.86 km./hr.). These speeds correspond to a slow, a comfortable, and a moderately fast walk. The values for each subject given in Tables 2 through 5 are mean values based on a series of runs.

TABLE 1.—*Height and Weight of Subjects*

Subject	Age	Height	Weight
Men			
1	26	5′6″	145
2	26	6′0″	185
3	25	6′0″	
4	22	5′11″	180
5	32	5′10½″	155
6	22	6′3″	190
7	19		
8	35	5′7″	145
9	23	6′0″	197
10	24	5′11½″	162
Women			
11	21	5′6½″	126
12	21	5′4″	123
13	21	5′2½″	120
14	21	5′4″	132
15	22	5′5½″	118
16	21	5′5½″	115
17	21	5′8″	131
18	22	5′8″	118
19	22	5′6″	125
20	22	5′3½″	127

Variable Differential Transformer

To measure the transverse rotations a variable differential transformer (VDT) was used, which had a special mount to convert the angular motion of the rotations to linear motion. This device has been described by Sabanas and Porter (*11*).

The VDT could record a maximum range of 50 deg. Before and after the study, the instrument was calibrated on a rotary table over a range of 40 deg., and for this range it was found to be linear.

A Tektronix storage oscilloscope (Model 564), equipped with a Polaroid Land camera, Type 47, and Polaroid film, Type 3000, were used. Records were made with oscilloscope sweep speeds of 0.2 sec./cm., 0.5 sec./cm., and 1.0 sec./cm. (Fig. 1 and 2).

For measuring pelvic and shoulder girdle rotation, the VDT was mounted on a parallelogram (Fig. 3), which adjusted to the vertical displacement of about 2 in. that occurs with normal walking. The VDT was then connected to a shoulder clamp or pelvic belt by a copper bellows shaft (Fig. 4 and 5). The bellows shaft provided a linkage that

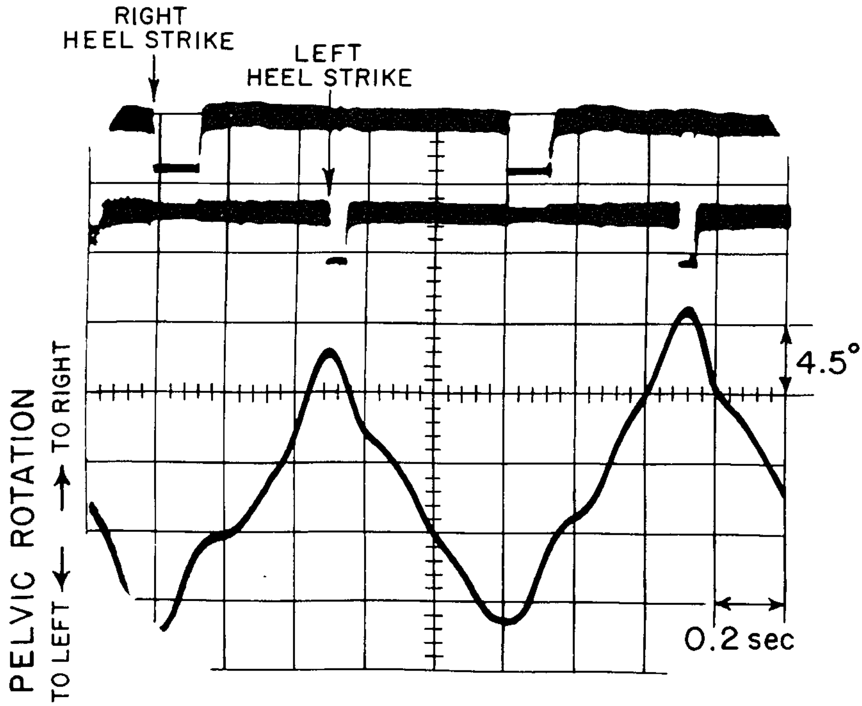


FIGURE 1.—Typical record of rotation and heel contact.

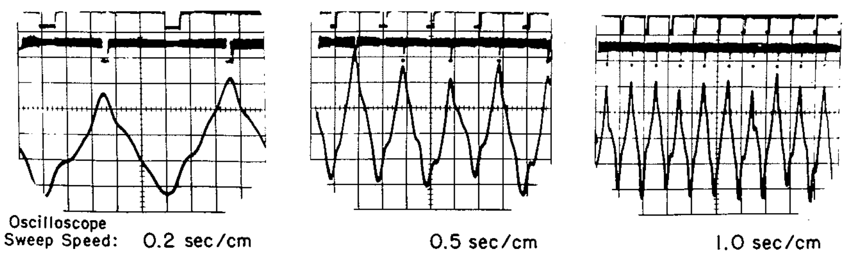


FIGURE 2.—Typical curves for pelvic rotation at 5.86 km./hr.

could be flexed in multiple directions to allow the subject some leeway as he walked on the treadmill. At the very extremes of flexion of the bellows shaft, artifacts appeared on the record. However, keeping the bellows in a more or less vertical position while measurements were made eliminated the artifacts.

The subjects had to walk in a relatively limited area (with about 4 in. of fore-and-aft wander allowable) of the treadmill, because they

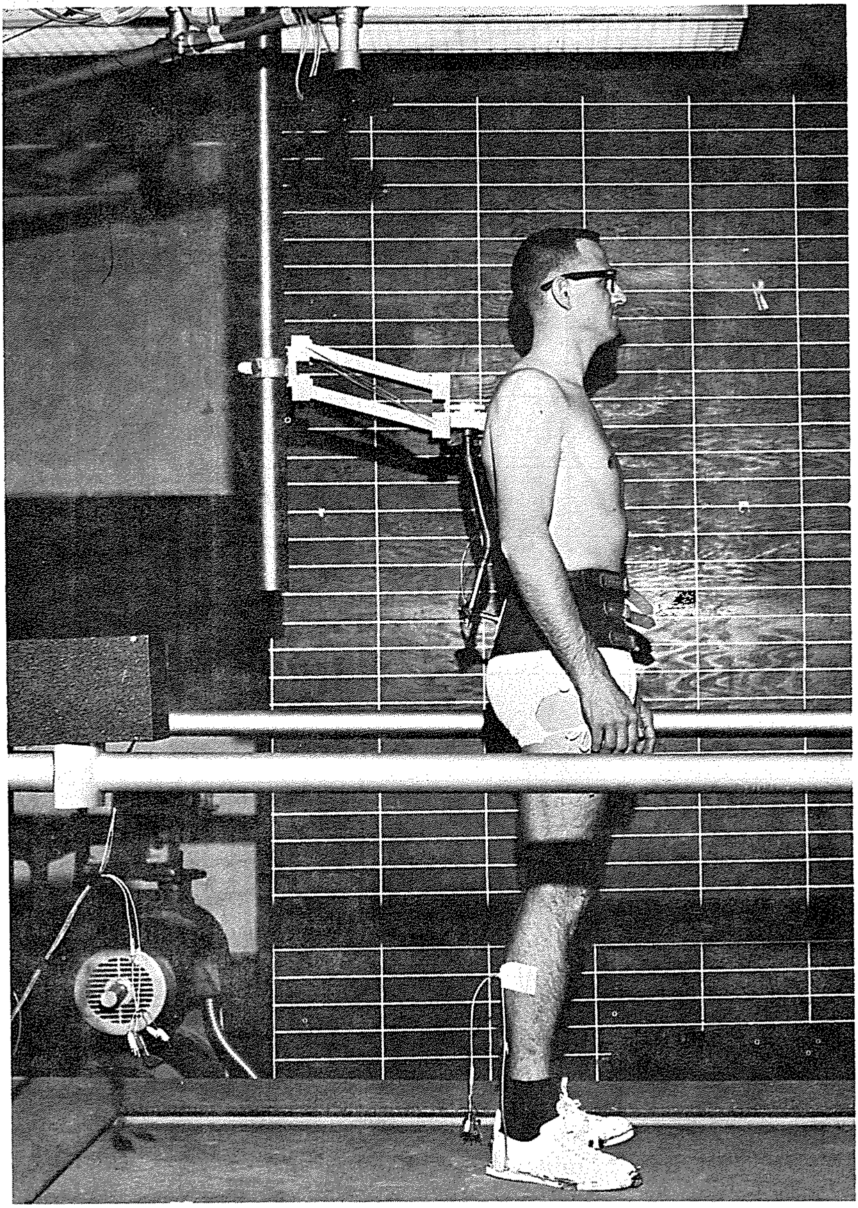


FIGURE 3.—Subject standing on treadmill. Note parallelogram with variable differential transformer (VDT) mounted on it.

were tethered to the parallelogram except when combined shoulder and pelvic rotations were measured. After a short period of adjustment, the subjects were able to walk comfortably within these limitations.

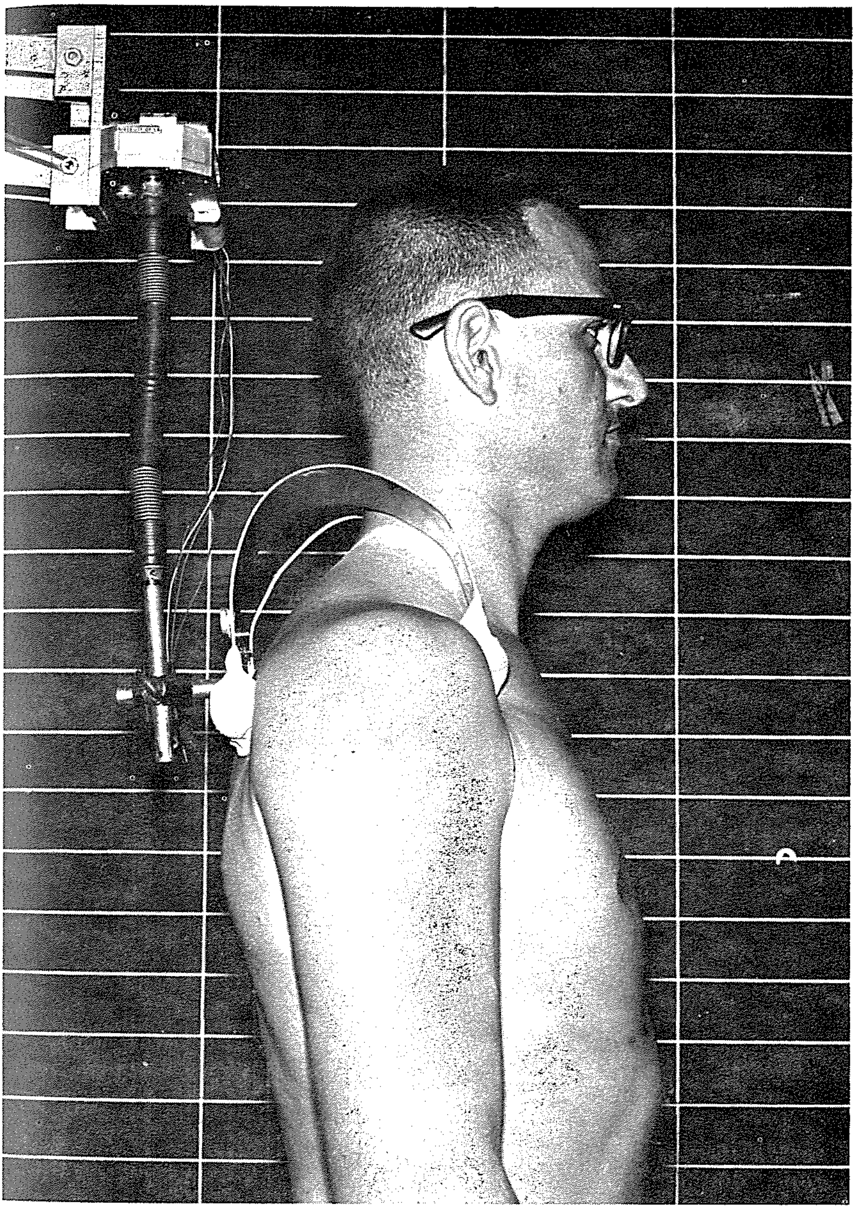


FIGURE 4.—Subject with shoulder-girdle clamp in place. VDT is attached to parallelogram; copper bellows shaft connects VDT and shoulder-girdle clamp.

Footwear and Attachments to Pelvis and Shoulder Girdle

In order to standardize footwear, all subjects wore canvas tennis shoes while walking on the treadmill. Heel strike was recorded separately for

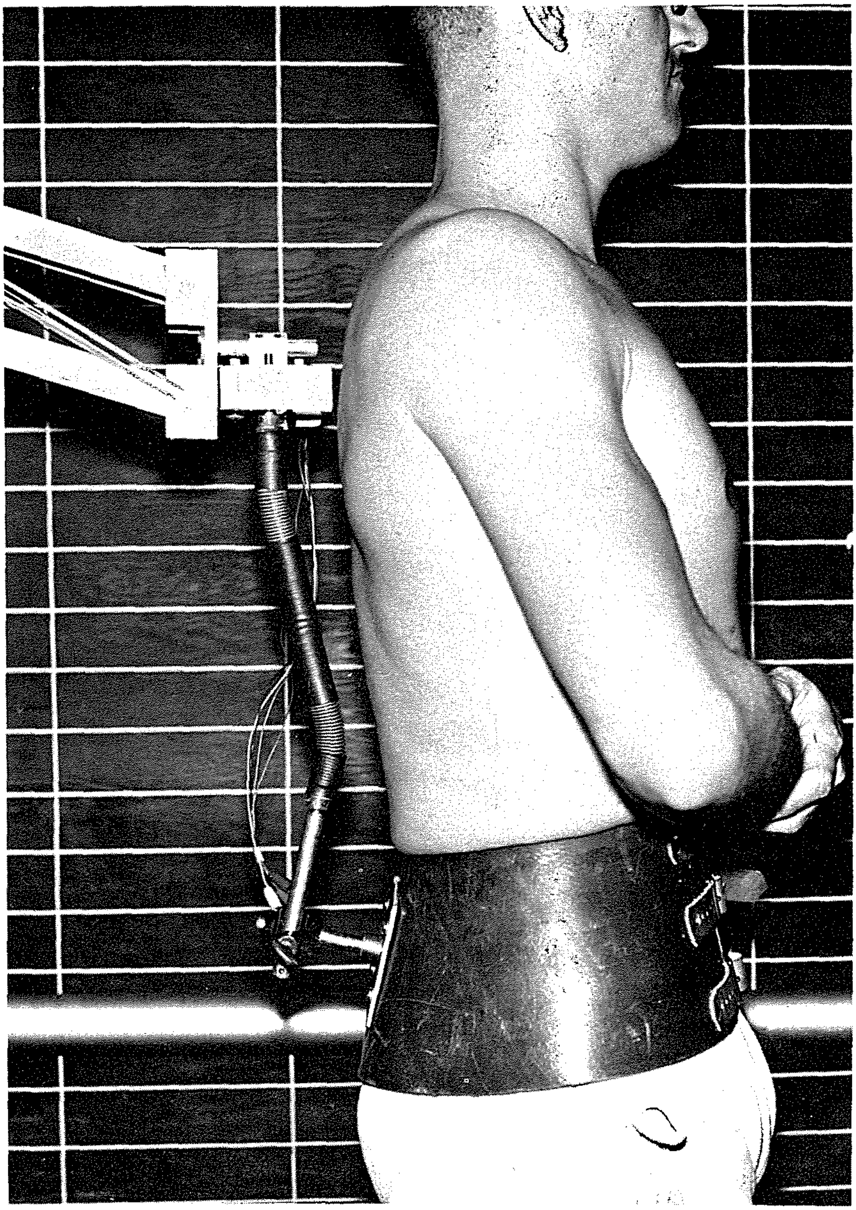


FIGURE 5.—Subject with pelvic belt in place. Copper bellows shaft connects VDT and pelvic belt.

each foot by means of a contact switch mounted on the heel of the tennis shoe.

The pelvic belt was a broad piece of snugly fitted leather with adjustable straps (Fig. 5). The shoulder clamps gripped the subject's shoulders in the infraclavicular area, anteriorly over the coracoid process and posteriorly over the infraspinous fossa. The two shoulder clamps were connected by a rigid crossbar (Fig. 6) ; this arrangement provided firm fixation.

In utilizing a device of this type the authors assumed that scapular motion reflected shoulder-girdle motion and that individual shoulder motion was symmetrical.

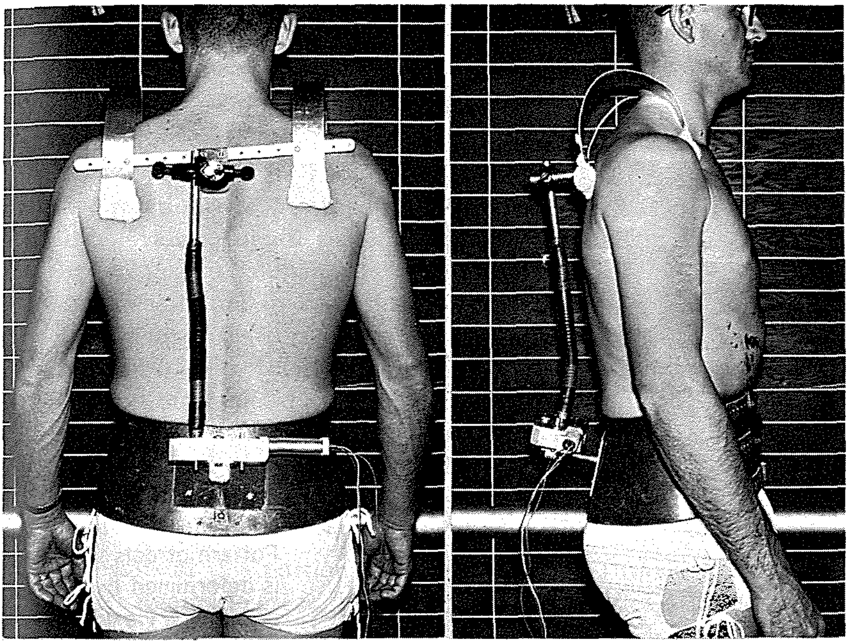


FIGURE 6.—Subject with both pelvic belt and shoulder-girdle clamp in place. Two shoulder clamps are connected by rigid crossbar. VDT is mounted on pelvic belt; it is connected to shoulder clamp by copper bellows shaft.

Goniometer

Trial runs were conducted in which a remote-readout coded digital goniometer was used to quantitatively observe transverse rotation of the scapula and of the upper thoracic and lower lumbar parts of the spine. The goniometer consists of a small lightproof balsa wood box, on the back side of which is mounted a grid, consisting of seven rows of interrupted horizontal slits (Fig. 7). On the front of the box is mounted a vertical viewing slit. When the instrument is used to measure angular rotations, the grid on the rear of the box is illuminated, and this illuminated grid is observed or photographed from a distance through the viewing slit in the front of the box. The observer sees a vertical array of dots of light in the viewing slit, one dot wherever one of the illuminated horizontal slits is directly in line with the viewing slit. The box and the grid of horizontal slits are proportioned in such a manner that for each degree of rotation of the box about an axis parallel to the viewing slit, a different and unique pattern of light dots will appear in the viewing slit, over a total range of 30 deg.

With use of a specially designed platform, the goniometer was mounted on a Steinmann pin inserted into the acromion. Motion pictures were then made at a distance of 20 ft. At this distance, 4.2 in. of fore-and-aft wander produced an artifact representing 1 deg. of rotation.

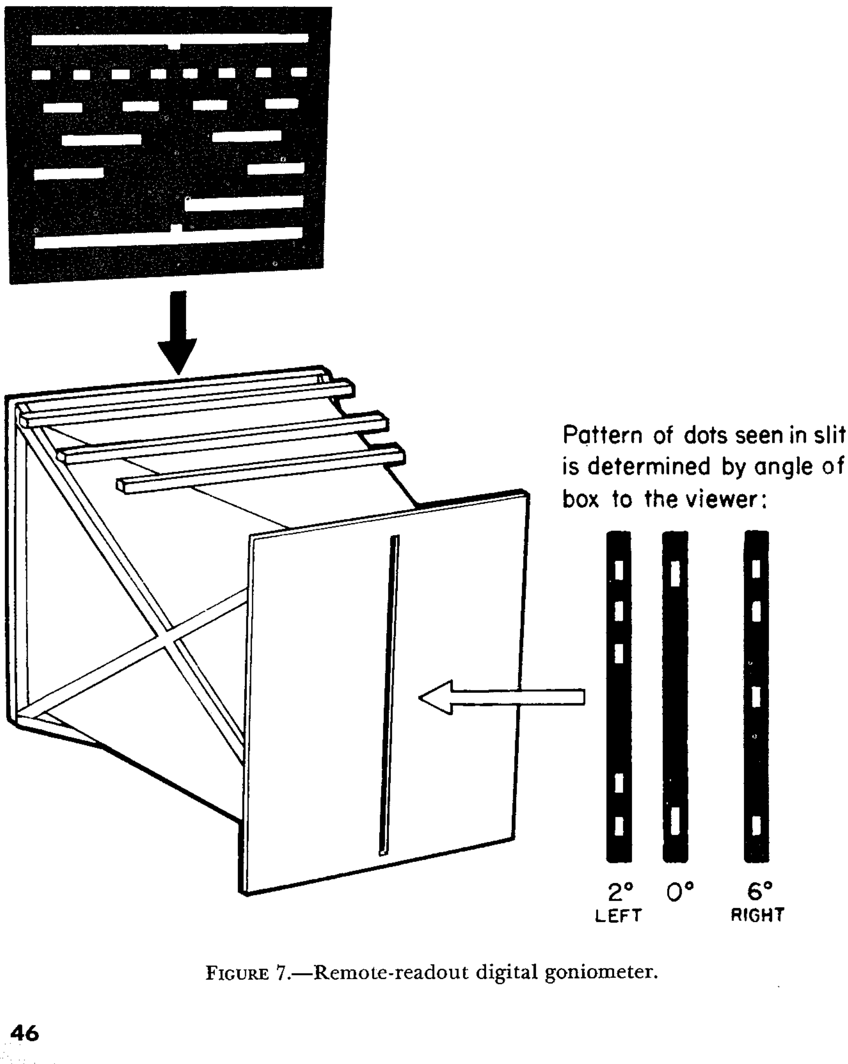


FIGURE 7.—Remote-readout digital goniometer.

For other runs, the goniometer was mounted on Steinmann pins inserted into the spinous processes of the upper thoracic and lower lumbar parts of the spine.

This technique for measuring rotation was generally unsuccessful because of excessive "whip" in the pins (see Section IV. DISCUSSION). However, the principal advantage of this technique over previous photographic methods for measuring rotations is that measurements in degrees can be made directly from the motion pictures and no elaborate reduction of data is necessary.

III. RESULTS

Transverse Rotation of the Pelvis

The mean values for transverse rotation of the pelvis in the male and female subjects walking on the level treadmill at 2.93, 4.39, and 5.86 km./hr. are presented in Table 2. A definite increase in the amplitude of pelvic rotation was measured when the walking speed was increased: The mean values for all the subjects together were 7.6 deg. at 2.93 km./hr., 8.7 deg. at 4.39 km./hr., and 13.2 deg. at 5.86 km./hr. No great difference was found in amplitude of transverse pelvic rotation when men were compared with women at all speeds. Except for fast walking, the lowest values for total pelvic rotation during any given cycle were recorded in women and the highest in men.

The wide range of values noted in this study is attributed to biological variability, and was not unexpected.

Transverse Rotation of the Shoulder Girdle

The results of this portion of the study parallel those of the pelvis (Table 3). Again, no great difference in the amplitude of shoulder rotation was noted between men and women within each given walking speed. Of interest was a *decrease* in the amplitude of shoulder rotation with increase in walking speed. The amount of this decrease was small, however, and an opposite trend was noted in five subjects.

Again, the range of recorded values was widespread; the lowest values were found in women and the highest in men.

Transverse Counterrotation of the Shoulders and Pelvis

These results (Table 4) also showed no great difference between the mean values for rotation in men and in women. With increasing walking speed, there was a significant increase in shoulder and pelvic counterrotation—from a mean of 9.9 deg. at 2.93 km./hr. to 17.0 deg. at 5.86 km./hr.

The sums of the independently measured transverse rotations of the pelvis and of the shoulder girdle—during walking at 4.39 km./hr.—in almost all cases exceeded the shoulder-girdle/pelvic counterrotation measured directly (Table 5).

Analysis of the Rotation Curves

Typical individual curves as photographed from the oscilloscope screen are illustrated in Figure 8. Several characteristics are evident in the pelvic curves. The reversal point of rotation from outward to inward occurred at toe-off. The pelvis rotated in an undulating manner, with, on occasion, even slight temporary reversals in direction of rota-

TABLE 2.—*Transverse Pelvic Rotation (mean individual values, degrees)*

Subject	Walking at 2.93 km./hr. (slow walk)	Walking at 4.39 km./hr. (natural walk)	Walking at 5.86 km./hr. (fast walk)
Men			
1	6.5	9.0	18.2
2	6.4	6.3	7.4
3	12.7	8.8	13.4
4	6.0	4.2	5.6
5	6.1	5.4	10.9
6	10.8	9.2	13.9
7	8.7	9.2	14.0
8	7.8	8.0	14.8
9	8.8	9.1	11.0
10	11.9	18.3	19.6
Mean	8.6	8.8	12.9
Range	6.0–12.7	4.2–18.3	5.6–19.6
Women			
11	4.0	7.5	9.2
12	7.6	11.1	23.8
13	7.0	10.8	15.8
14	6.6	11.2	15.9
15	4.0	5.0	14.1
16	11.8	11.8	15.0
17	7.9	9.9	18.1
18	5.8	5.0	7.0
19	7.2	10.1	12.5
20	4.2	3.6	4.4
Mean	6.6	8.6	13.6
Range	4.0–11.8	3.6–11.8	4.4–15.9
Overall mean value of rotation for both men and women	7.6	8.7	13.2

TABLE 3.—*Transverse Shoulder Rotation (mean individual values, degrees)*

Subject	Walking at 2.93 km./hr. (slow walk)	Walking at 4.39 km./hr. (natural walk)	Walking at 5.86 km./hr. (fast walk)
Men			
1	9.4	8.0	7.1
2	13.6	11.0	15.9
3	5.8	6.4	7.3
4	4.8	4.8	3.1
5	8.2	5.1	4.5
6	9.3	6.9	5.1
7	9.6	4.9	4.5
8	7.7	6.4	6.6
9	11.8	8.2	6.7
10	7.6	5.5	4.1
Mean	8.8	6.7	6.5
Range	4.8–13.6	4.8–11.0	3.1–15.9
Women			
11	5.6	6.9	6.7
12	9.5	9.2	4.7
13	4.3	4.0	4.9
14	7.6	6.2	4.4
15	3.8	3.0	3.2
16	8.2	7.5	5.2
17	7.0	4.9	6.3
18	8.7	4.0	2.0
19	4.3	4.9	4.1
20	9.0	8.2	9.3
Mean	6.8	5.9	5.1
Range	3.8–9.5	3.0–9.2	2.0–9.3
Overall mean value of rotation for both men and women	7.8	6.3	5.8

tion. These undulations tended to be symmetrical and repetitive in any one subject at any given speed of walking (Fig. 9).

It was also noted that the similarity of the rotation curves increased with an increase in the speed of walking (Fig. 10). At the moderately fast walk of 5.86 km./hr., the pattern of rotation was sufficiently consistent and individualized that male and female patterns were distinguishable (Fig. 11 and 12). The female pelvic rotation tended to have sharper peaks and valleys (major reversal points), with more pronounced changes between these points.

It is our belief that the characteristics of these curves do not result

TABLE 4.—*Transverse Shoulder-Pelvic Counterrotation*
(mean individual values, degrees)

Subject	Walking at 2.93 km./hr. (slow walk)	Walking at 4.39 km./hr. (natural walk)	Walking at 5.86 km./hr. (fast walk)
Men			
1	11.2	15.3	21.0
2	12.4	16.8	20.0
3	14.8	13.6	17.7
4	7.1	7.3	6.6
5	8.6	14.8	21.5
6	7.4	10.3	14.9
7	10.1	12.3	11.8
8	8.5	9.6	13.7
9	11.9	13.0	18.8
10	13.9	17.0	23.7
Mean	10.6	13.0	17.0
Range	7.1–14.8	7.3–17.0	6.6–23.7
Women			
11	8.1	11.8	13.4
12	8.8	13.6	19.4
13	9.4	14.1	18.7
14	9.0	14.4	21.0
15	3.0	5.0	12.0
16	10.2	14.2	18.5
17	7.7	14.0	19.4
18	5.9	6.0	8.4
19	6.6	10.8	17.9
20	13.2	20.0	20.7
Mean	8.2	12.4	16.9
Range	3.0–13.2	5.0–20.0	8.4–21.0
Overall mean value of rotation for both men and women	9.4	12.7	17.0

from electrical artifacts produced by the apparatus, since the results of earlier studies (*2*), recorded with a direct photographic technique, reveal a similar pattern. It should be noted, however, that that study was of male subjects only. Similar patterns appear in the shoulder rotation and shoulder-pelvic counterrotation studies (see Fig. 8).

No further objective or mathematical evaluation of the rotation curves was carried out. No results are reported from the studies made with the goniometer since the technical difficulties made reliable data unobtainable.

TABLE 5.—*Sum of Pelvic and Shoulder Rotations Measured Separately Compared with Shoulder-Pelvic Counterrotation Measured Directly (mean individual values, degrees)*

Recorded at 4.39 km./hr.

Subject	Shoulder rotation	Pelvic rotation	Sum	Shoulder-pelvic counterrotation	Difference
Men					
1	8.0	9.0	17.0	15.3	1.7
2	11.0	6.3	17.3	16.8	0.5
3	6.4	8.8	15.2	13.6	1.6
4	4.8	4.2	9.0	7.3	1.7
5	5.1	5.4	10.5	14.8	−4.3
6	6.9	9.2	16.1	10.3	5.8
7	4.9	9.2	14.1	12.3	1.8
8	6.4	8.0	14.4	9.6	4.8
9	8.2	9.1	17.3	13.0	4.3
10	5.5	18.3	23.8	17.0	6.8
Women					
11	6.9	7.5	14.4	11.8	2.6
12	9.2	11.1	20.3	13.6	6.7
13	4.0	10.8	14.8	14.1	0.7
14	6.2	11.2	17.4	14.4	3.0
15	3.0	5.0	8.0	5.0	3.0
16	7.5	11.8	19.3	14.2	5.1
17	4.9	9.9	14.8	14.0	0.8
18	4.0	5.0	9.0	6.0	3.0
19	4.9	10.1	15.0	10.8	4.2
20	8.2	3.6	11.8	20.0	−8.2
Mean	6.3	8.7	7.3	12.7	4.6

IV. DISCUSSION

It was the purpose of this study to quantitate certain transverse rotations of the trunk in human locomotion in an attempt to provide further and comparative information on the values of these rotations in men and women. Another purpose of the study was to test several new experimental techniques for making such measurements.

For this type of biological measurement, the VDT was found to have the advantages of portability, adaptability, sturdiness, and sufficient range and accuracy. Combined with a storage oscilloscope and Polaroid camera, it served as a means for recording measurements simply and quickly. However, precise measurement of time intervals was difficult because of the small size of the photographs. Rotations could easily be

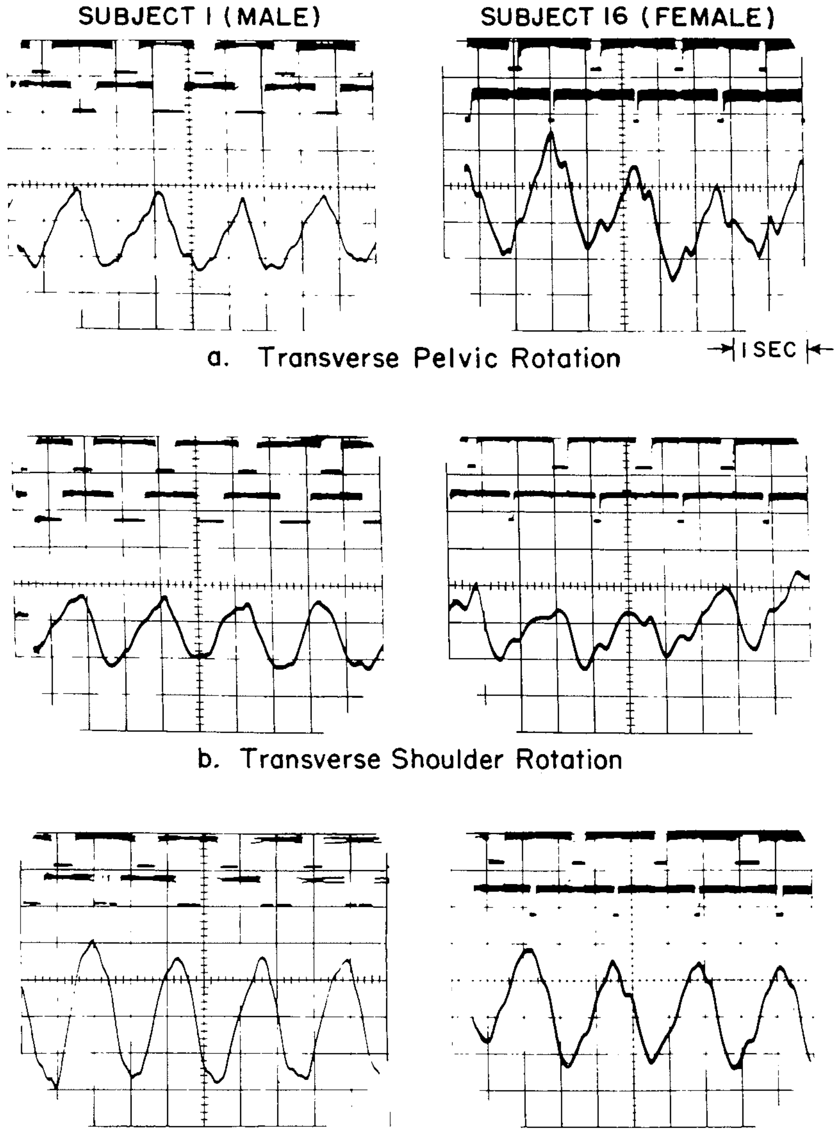
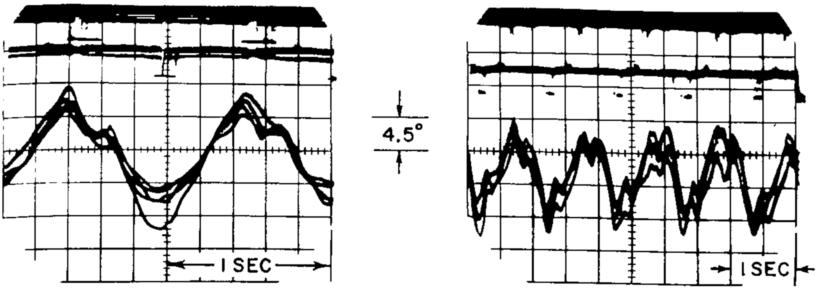


FIGURE 8.—Typical curves of transverse pelvic rotations in subjects 1 (male) and 16 (female). Walking speed, 4.39 km./hr.

measured in degrees. This technique has subsequently been used successfully by Gregersen and Lucas (*5*) and Lumsden and Morris (*8*).

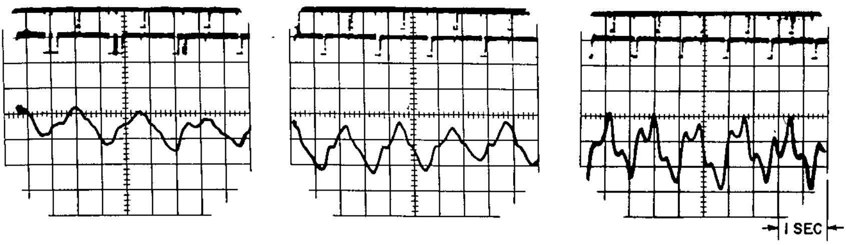
The only procedural disadvantage in using the VDT in locomotion studies is that the subject must be tethered by electrical wiring to the



a. Transverse Shoulder-Pelvic Counterrotation

b. Transverse Pelvic Rotation

FIGURE 9.—Reproducibility of rotation curves. *a,* superimposed successive curves of walking cycle at 4.39 km./hr. in subject 12 (female). *b,* similar superimposed curves of walking cycle at 5.86 km./hr. in subject 9 (male).



2.93 km/hr

4.39 km/hr

5.86 km/hr

FIGURE 10.—Transverse pelvic rotations in subject 11 (female), at 2.93, 4.39, and 5.86 km./hr. Note increasing symmetry of curves with increased speed of walking.

recording equipment. The goniometer was employed to circumvent this problem. However, because of instability of the goniometer on its mount on the Steinmann pin, no satisfactory results were obtained. Minor refinements, which would increase the stability of the goniometer and reduce its mass somewhat, would make it a very useful instrument. It would have the advantages of freeing the subject of any wire tethers and of providing data directly recordable in degrees. This has not been the case with previous photographic techniques (*3*).

For a comparison of our results with those of others, it should be noted that Ralston's energy expenditure studies (*10*) have shown that a walking speed of 4.39 km./hr. approaches the optimal walking speed of most healthy, average-sized adults. The free-cadence walking speed described in the work of Murray and co-workers (*9*) and in earlier studies at this laboratory (*2*) probably approaches this value.

Our average value of 8.7 deg. for transverse pelvic rotation (range

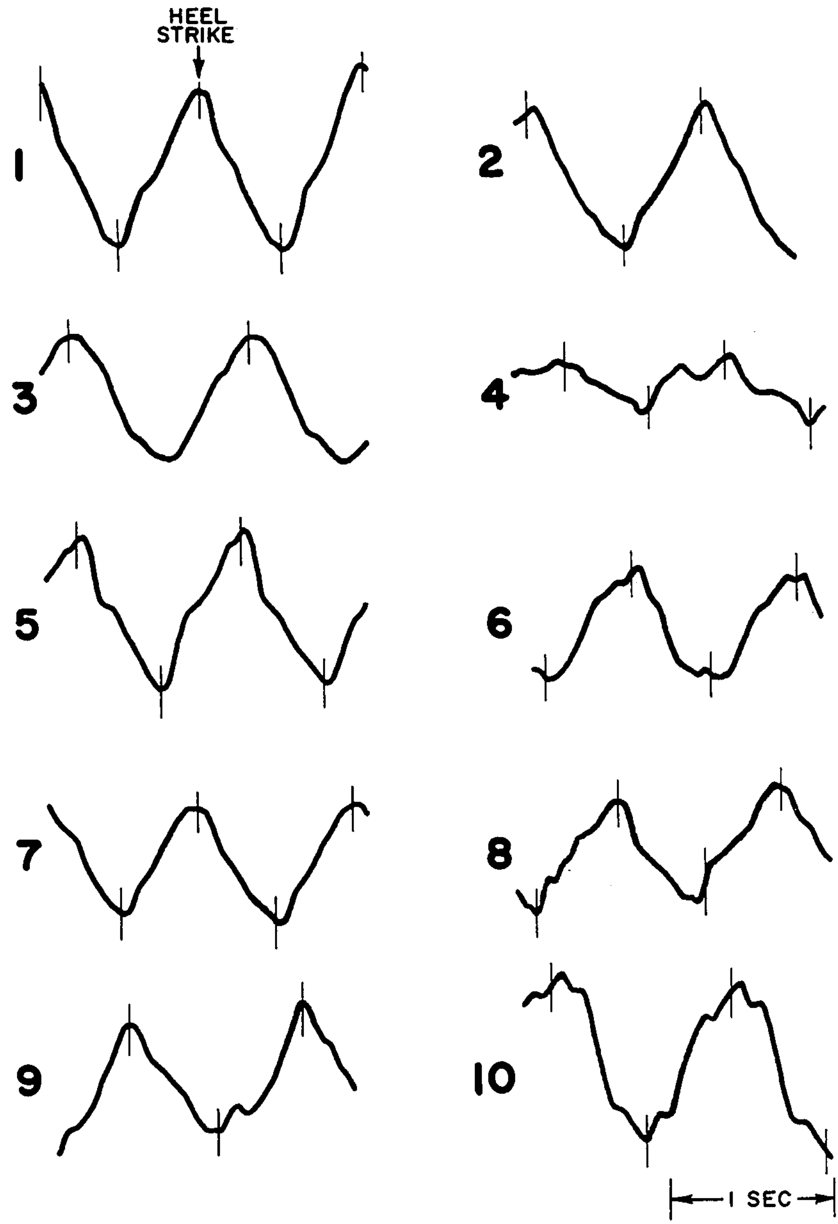


FIGURE 11.—Typical curves of transverse rotation of the pelvis (men—subjects 1–10) at a walking speed of 5.86 km./hr.

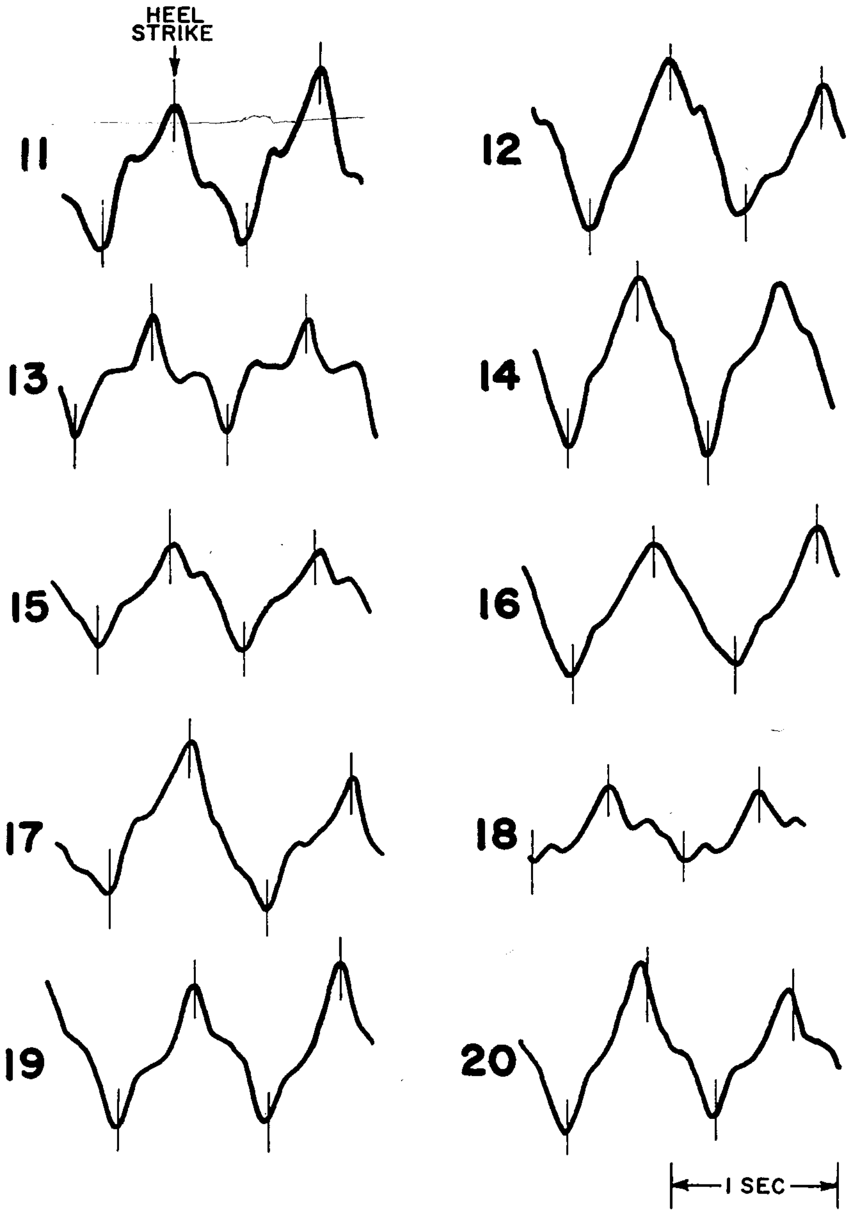


FIGURE 12.—Typical curves of transverse rotation of the pelvis (women—subjects 11–20) at a walking speed of 5.86 km./hr.

3.6–18.3 deg.) measured at the "comfortable" walking speed of 4.39 km./hr., is close to the value of 8 deg. (range 3.0–15.8 deg.) determined by Levens and co-workers (*7*), who, utilizing a photographic technique, studied 12 young men during walking on a walkway. Gregersen and Lucas obtained a value of 10.3 deg. using a technique similar to the authors' (with minor modifications) and identical walking speeds. Murray and associates (*9*) recorded a value of 10 $\pm$3.5 deg. for transverse pelvic rotation in 60 normal men during free-cadence walking. Some subjects were noted to have no transverse pelvic rotation. The authors deduced from this finding that transverse pelvic rotation is not an obligatory motion and that the degree of rotation during comfortable walking is due primarily to individual characteristics.

Murray and associates recorded a value of 6.9 $\pm$1.9 deg. for thoracic rotation during free-cadence walking. They recorded this by photographing a target on a wand strapped to the sternum by elastic webbing about the thorax. Their measurements are in close agreement with the authors' for shoulder rotation (6.3 deg.) with the subjects walking at 4.39 km./hr. Gregersen and Lucas recorded 5.8 deg. of shoulder-girdle rotation at the same speed. At the T-1 level, under the same conditions, the latter investigators recorded a rotation of 5.1 deg., 0.7 deg. less than that of the shoulders. The closeness of all these values suggests that all three groups of investigators were evidently measuring upper thoracic rotation; the results indicate that the shoulder girdle probably rotates with the upper part of the thorax. This was our hypothesis when we designed our device for measuring shoulder rotation. The points of attachment of our shoulder device were the coracoid process and the infraspinous fossa of the scapula. Hence the actual motion of the tip of the shoulder was not measured. Also the device forced the shoulders to rotate as one rigid unit. (It is not known whether independent motion of the two halves of the shoulder girdle on the thorax occurs; if this is so, the values recorded by the shoulder-clamp device as a reflection of shoulder rotation would be suspect. This question could be readily solved by simultaneously photographing rotations of the shoulder and the pelvis with either the goniometer or the pin and target attached.)

Observation of walking would lead one to expect the experimentally documented fact that pelvic rotation increases with an increase in walking speed. As walking speed increases, swing phase becomes longer in relation to stance phase and, more importantly, stride length increases. To achieve this increased stride length the pelvis contributes by increasing its transverse rotation. Murray and co-workers made a similar observation but did not measure transverse rotation at different speeds.

The greatest discrepancy in amount of rotation, both at the shoulder girdle and at the pelvis, was noted between a comfortable and a moderately fast walking speed. However, while transverse rotation of the pelvis was found to increase with an increase in walking speed, transverse rotation of the shoulder girdle decreased.

The role of this phenomenon in locomotion is not yet fully understood. Previous studies by Kurokawa and Inman (*6*) and Chapman and Ralston (*1*) indicate that the transverse rotations of the shoulders, as well as arm motion, are passive reactions to pelvic movement and probably serve to damp motion. Elftman (*4*) and Murray and co-workers (*9*) have also suggested that arm motion and rotation of the trunk may have a damping function.

If shoulder motion were an uncontrolled passive reaction to pelvic rotation transmitted up the trunk, one would expect shoulder rotation to increase in amplitude as pelvic rotation increased. This did not occur in any of the subjects in this study. This is probably because the musculature of the upper part of the trunk and the shoulders inhibits rotation of the shoulders and the trunk. The study by Kurokawa and Inman (*6*) confirms this observation in regard to shoulder and arm motion.

This damping phenomenon reduces and makes more gradual the total rotatory movements of the trunk and the pelvis. The effect may contribute to the efficiency of locomotion.

The damping effect could, however, be controlled passively—not by the musculature—and simply reflect the mechanical characteristics of the linkage provided by the trunk between the pelvis and the shoulder girdle. Illumination of this problem might be provided by further electromyographic studies, such as that done by Kurokawa and Inman, of the musculature of the upper part of the trunk and the shoulder girdle during locomotion.

The fact that the counterrotation of the shoulders and pelvis, as measured by adding the two independently determined values, was consistently greater than the value measured directly, is most easily explained by the observation that the shoulder-pelvic counterrotation is not exactly 180 deg. out of phase. Elftman has hinted at this possibility, and it could be expected if shoulder rotation is at least in part a passive response to pelvic transverse rotation transmitted up the trunk. In presenting this observation we must remind the reader again that our technique as carried out with the shoulder-clamp device measured motion primarily of the thorax and scapula. Also, it appears probable that pelvic and shoulder-girdle rotations are closer to being 180 deg. out of phase when the subject walks faster. It would therefore be of interest to make a comparison such as that described here but with the subjects walking at 5.86 instead of 4.39 km./hr.

A surprising finding in this study was the quantitative similarity between the average pelvic and shoulder rotations in the two sexes. Observations of men's and women's gait patterns led us to expect a greater amplitude of individual transverse rotations in women. On the contrary, most of the greatest individual rotations measured occurred in men.

Although quantitatively similar, men's and women's transverse rotations were found to be qualitatively different. Most intriguing were the actual brief reversals of rotation observed most consistently in women. Gross observations led us to believe that this reversal of rotation occurred shortly after heel-strike (probably during foot-flat). Comparison of the recorded curves also shows that the women tended to have more defined patterns. The reasons for these differences are not known; they might be the result of the greater movement of subcutaneous tissue that occurs in women during walking.

An attempt at quantitative analysis of the curves of rotation was carried out. No consistent amplitude and/or temporal occurrence could be identified. For any given subject the variations in the curves were fairly definite and could be characterized, but an attempt to generalize from all the subjects was not revealing because of the variability. Our inability to determine exactly the time of beginning and end of a given feature in the rotation curves no doubt contributed to the problem.

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